TEST REPORT:

REDI-ROCK BARRIER TESTING:
PHASE THREE Full-Scale Wall Tests

Tested By:
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1.0 Introduction

This report documents the performance and capacity of a statically-loaded, full-scale, vehicular barrier constructed from standard hollow core Redi-Rock system blocks. In this study two identical wall samples were constructed and tested with two different end constraint configurations. Barrier wall samples consisted of four courses of Redi-Rock Block as shown in **Figure 1**. Test walls were dry-stacked, steel reinforcing bars were placed, and then the cores were filled with concrete to create a solid barrier wall. The bottom course of blocks were gravel filled to mimic construction of a barrier on top of a retaining wall. Construction and testing was performed by Aster Brands at its testing facility located in Charlevoix, Michigan throughout the months of June to October, 2020. Redi-Rock is an Aster Brands company.

Figure 1 - Test Wall A (left) and Wall B (right)

2.0 Purpose

The objective of this test program was to verify the static load capacity and performance of a full-scale section of barrier wall. Secondary objectives included exploring possible failure mechanisms and providing data to calibrate mathematical models. No dynamic vehicle impact testing was completed and no attempt was made to consider barrier shape or texture on wall performance during vehicle impact.

3.0 Materials
Barrier walls for this test project were constructed from one Redi-Rock R-41HC retaining block at the base and the stem consisted of two courses of Redi-Rock Hollow Core Freestanding Blocks (F-HC).

Redi-Rock R-41HC blocks **(Figure 2)** are wet-cast concrete, precast modular block (PMB) units with a nominal width of 40½ inches (1,029 mm), length of 46⅛ inches (1172 mm), and height of 18 inches (457 mm). These blocks are cast with void areas in the center and on the sides of the block. Test blocks were cast with a low-profile, smooth face texture. No attempt has been made to account for any contribution from the additional concrete that would be in a standard Redi-Rock face texture. Typical block weight (with Ledgestone texture) is about 1,620 lb (735 kg). Average test block weight was 1,442 lb (654 kg). Precast blocks did not contain reinforcing steel.

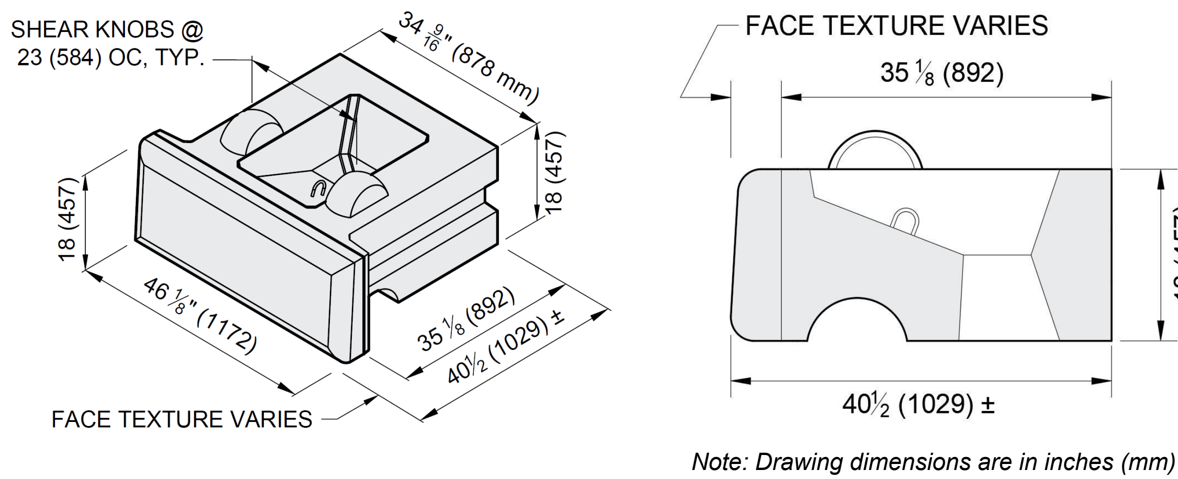

Figure 2 - R-41HC Block and Cross Sectional Depiction

Redi-Rock F-HC blocks **(Figure 3)** are wet-cast concrete, precast modular block (PMB) units with a nominal width of 24 inches (610 mm), length of 46⅛ inches (1172 mm), and height of 18 inches (457 mm). These blocks are cast in a standard freestanding block form with inserts to create hollow cores through the block. Test blocks were cast with a low-profile, smooth face texture. No attempt has been made to account for any contribution from the additional concrete that would be in a standard Redi-Rock face texture. Block weight (with Ledgestone texture) is about 770 lb (350 kg). Average test block weight was 447 lb (203 kg). Precast blocks do not contain reinforcing steel.

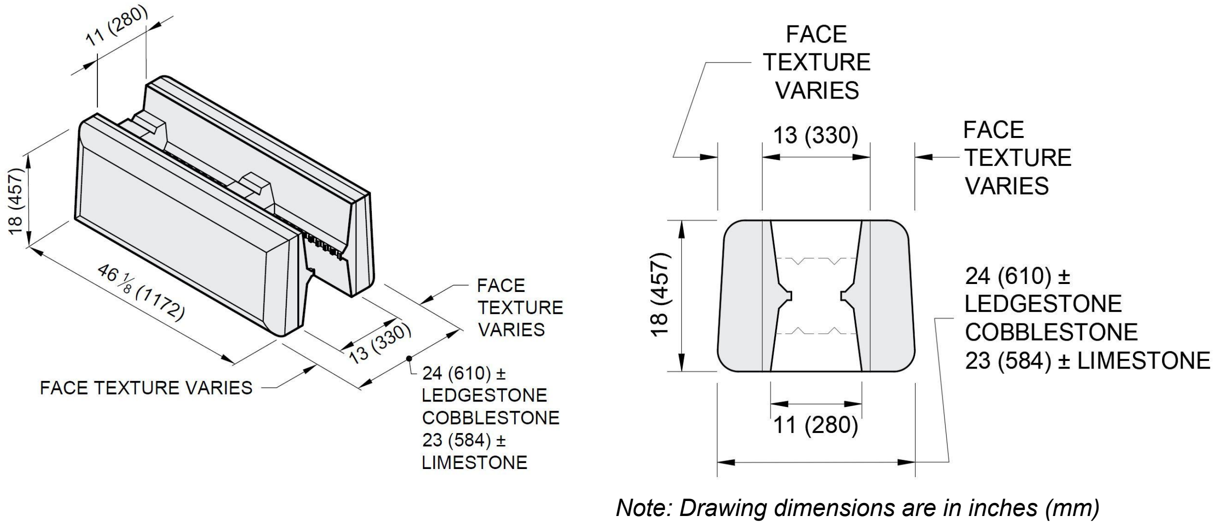

Figure 3 - F-HC Block and Cross Sectional Depiction

Concrete blocks used in this series of testing were produced by Aster Brands at its testing facility located in Charlevoix, Michigan. Blocks were cast from redi-mix concrete with a target compressive strength of 4,000 psi (27.6 MPa). The blocks were cast and cured inside a heated facility for a minimum 21 days before construction of the barrier walls began. All blocks were cured a minimum 28 days before the wall samples were tested. Compressive strength of the concrete used to produce the test blocks, taken at the actual test date, ranged from 3,300 psi (22.8 MPa) to 4,950 psi (34.1 MPa), as determined by ASTM C39 on 4-inch by 8-inch (102 mm by 203 mm) field-cured concrete cylinder specimens. Block strengths for each test wall are shown in **Figures 4 and 5**.

Concrete infill used to fill the cores of the wall samples was a pumpable concrete mix with a target compressive strength of 4,000 psi (27.6 MPa). Concrete infill was placed into wall cores in two lifts. Concrete infill in the wall bases (R-41HC) was placed on 9/21/2020 and in the wall stems (F-HC) on 9/23/2020. Concrete infill was allowed to cure a minimum of 8 days before barrier wall testing began. The average concrete infill compressive strength at the actual test dates was 4,140 psi (28.5 MPa) in the wall base to 3,780 psi (26.1 MPa) in the wall stem. Compressive strength was determined by ASTM C39 on 4-inch by 8-inch (102 mm by 203 mm) field-cured concrete cylinder specimens. Concrete infill strengths for each test wall are shown in **Figures 4 and 5**.

Reinforcing steel used in the construction of the test walls was specified as ASTM A615 - Grade 60, uncoated bars. Structural reinforcement was #6 (19.1 mm) bar. Stirrups were fabricated from #4 (12.7 mm) bar. Reinforcement was cut and bent per specified drawings by Striker Concrete Supply located in Traverse City, Michigan. None of the rebar was field cut or bent.

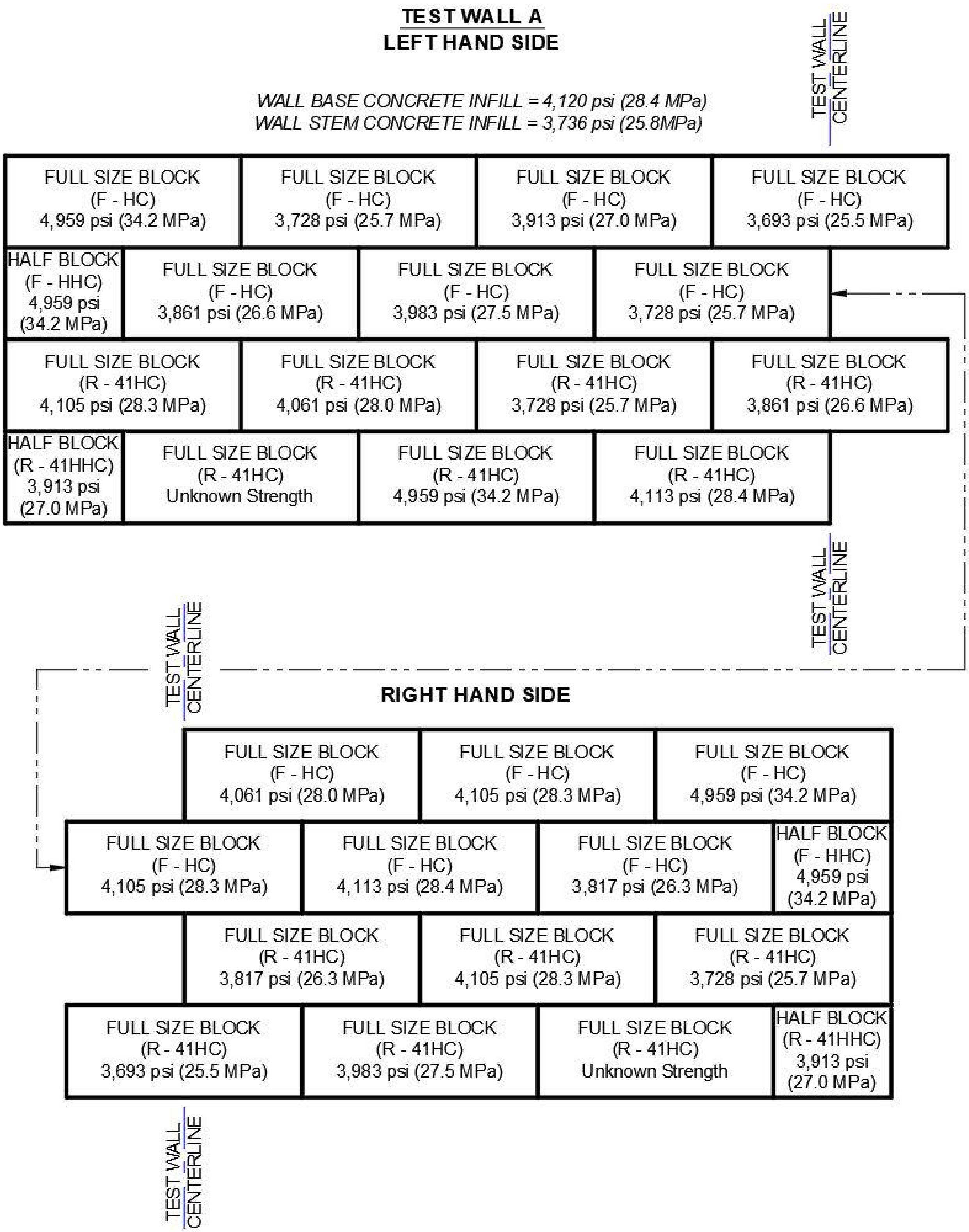

Figure 4 - Wall A Concrete Compressive Strengths
(looking from the front of the wall sample)

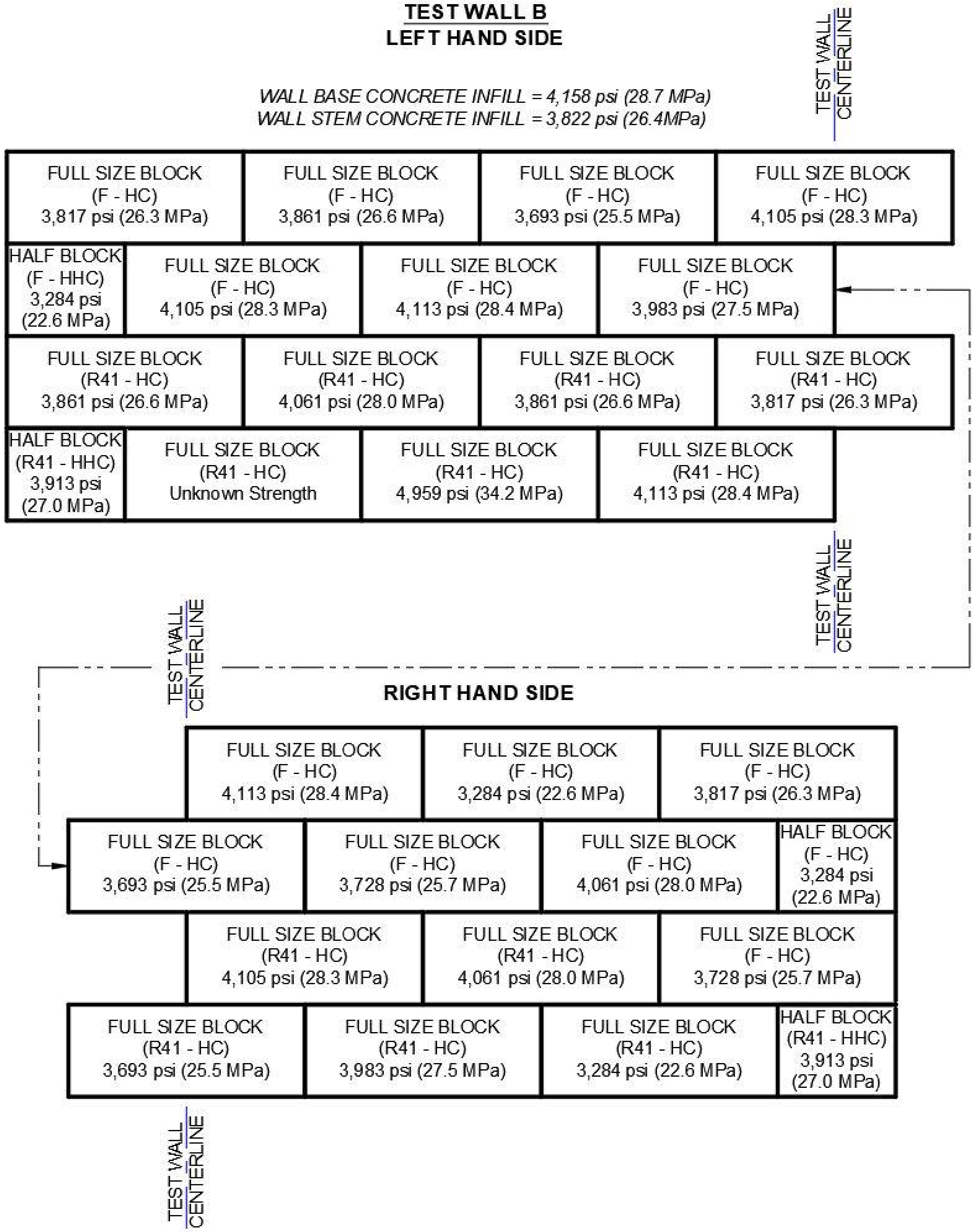

Figure 5 - Wall A Concrete Compressive Strengths (looking from the front of the wall sample)

Cores of the bottom course of blocks and space between the blocks were infilled with ¾-inch (19-mm), 100% crushed limestone, approximately meeting the gradation of ASTM No. 57 stone. The crushed stone was placed in a single lift, screeded level, and tamped. The crushed stone material used as infill exhibited the grain-size distribution as shown in **Table 1**.

Table 1 - Infill stone grain size distribution

Sieve Size		Percent Passing
U.S.	mm	
1.5-inch	37.5	100
1-inch	25	100
¾-inch	19	93
½-inch	12.5	61
⅜-inch	9.5	36
No. 4	4.75	8
No. 8	2.36	4
No. 200	0.075	1.8

4.0 Barrier Wall Design

A total of two identical test walls were constructed for this portion of the test. Block layout, bond pattern, steel reinforcement, and construction detailing were the same for each wall and can be seen in **Figures 6** through **9.**

Test Walls A and B had a standard running bond with a joint centered in the middle of the test specimen. Test samples were reinforced both horizontally and vertically with with #6 (19.1mm) reinforcement. Two bars were placed horizontally in the horizontal cores of each course of F-HC blocks. This reinforcement helps to spread load laterally along the length of the wall. There were also (8) #6 vertical bars, per block, spaced in four pairs across the width of the wall. These bars were extended into the base block below, where possible, to connect the stem to the base. Where not, the rebar ended at the bottom of the stem. Four #4 (12.7mm) U-shaped stirrups per block finished the top of the wall and were placed 1” clear from the top.

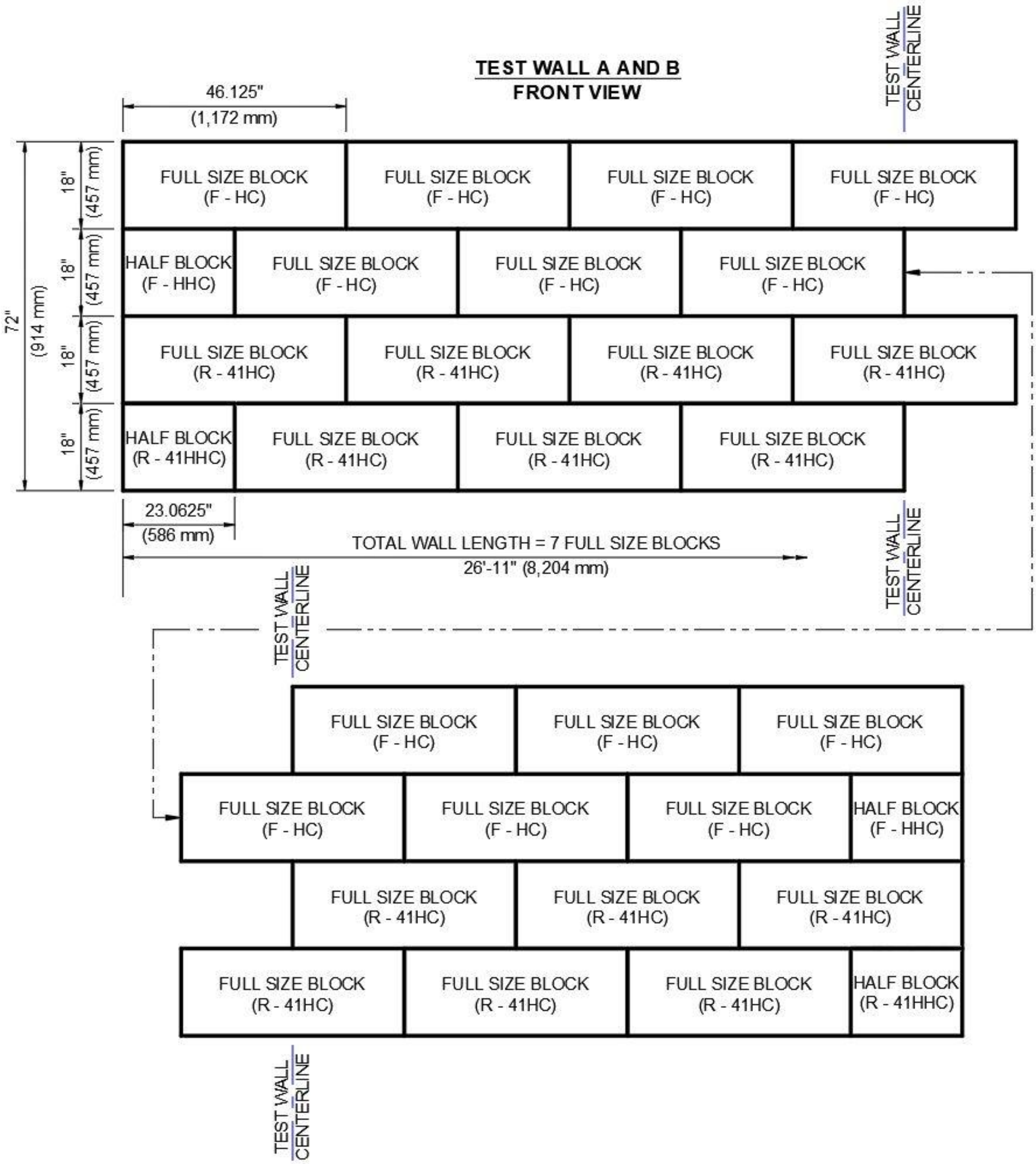

Figure 6 - Test Block Layout

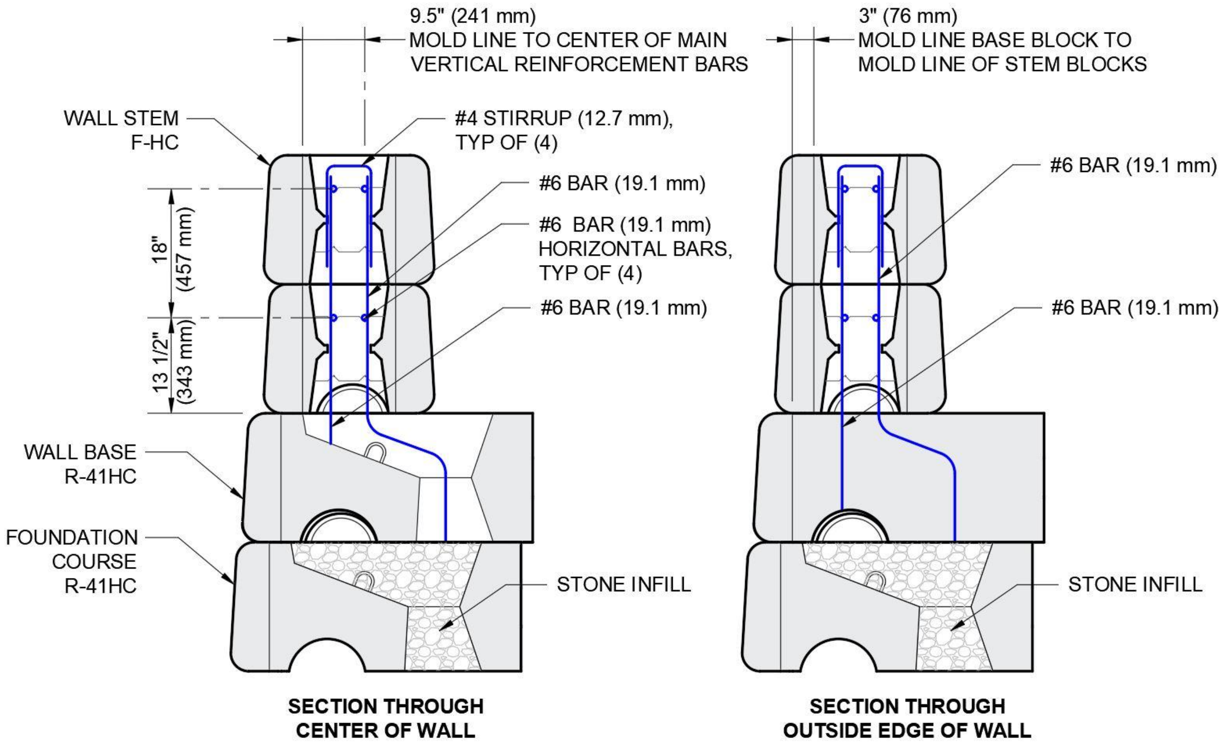

Figure 7 - Wall Cross Sections

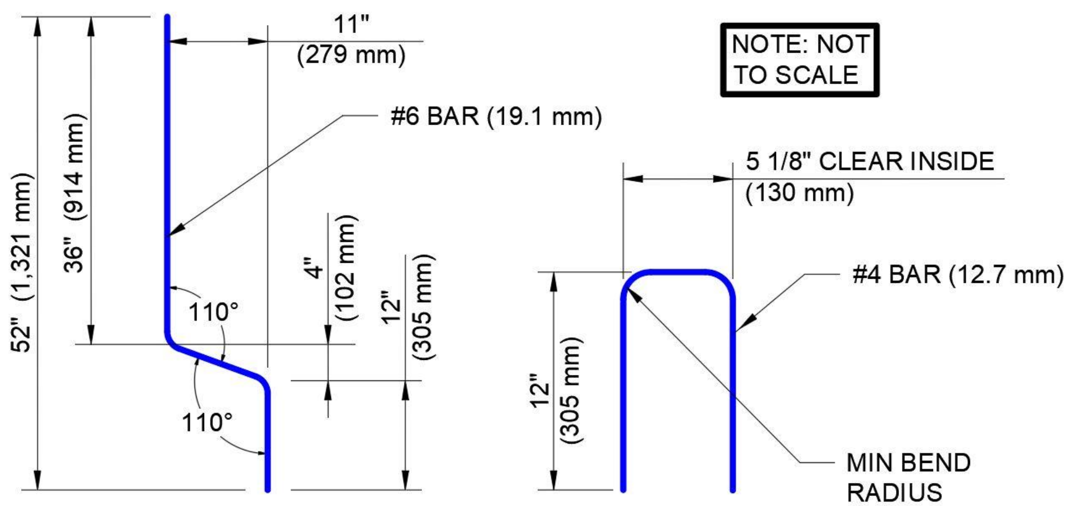

Figure 8 - Rebar Details. Bent Reinforcement Bars and U-Shaped stirrups.

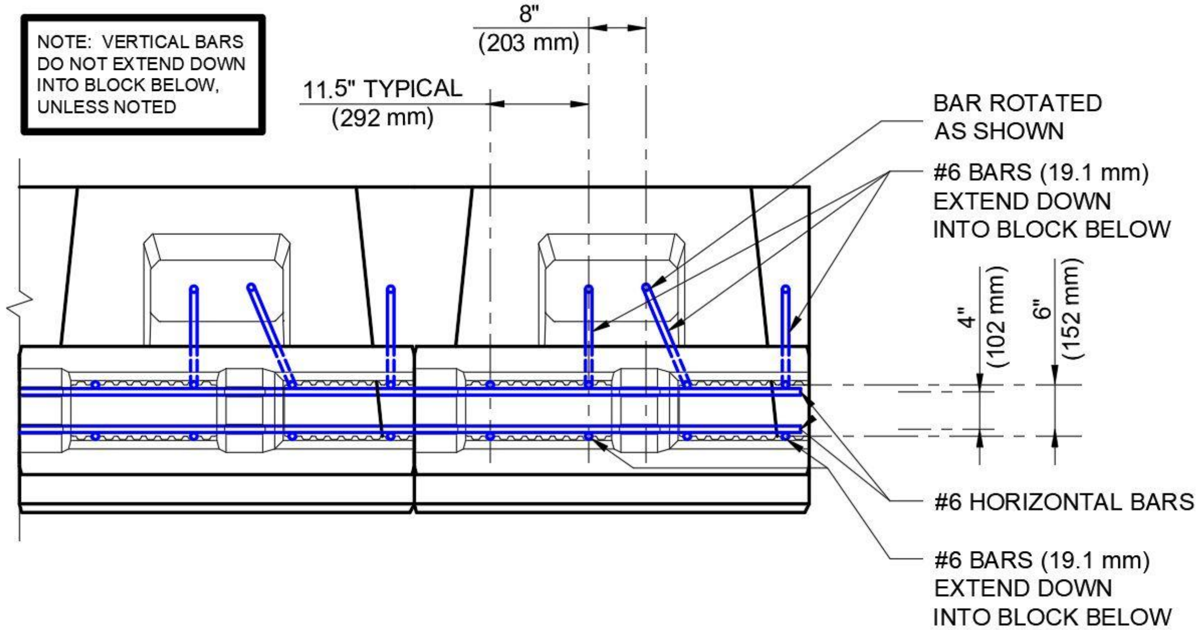

Figure 9 - Top down view of test walls

5.0 Barrier Wall Construction

Barrier wall sections were constructed inside the structural testing frame in the Aster Brands testing facility (**Figure 10)**. Walls were constructed by first placing a course of R41-HC blocks as a foundation for the barrier wall. The ends and back of this course were enclosed with wooden formwork and the cores and voids between the blocks were filled with stone aggregate. A second course of R41-HC blocks were then stacked in a running bond on top of the foundation course. The ends and back of this course were also enclosed with wooden formwork to contain concrete infill between the blocks.

Two courses of F-HC hollow core freestanding blocks (courses three and four) were then stacked on top of this retaining block to form the barrier wall stem section. After the walls were dry stacked, rebar was placed in the cores and tied in place with standard, uncoated wire ties. The outside edges of the walls were then formed and braced with wooden formwork. Joints were lightly tuck pointed on the outside with non-shrink grout to seal all joints before filling the cores with infill concrete.

Once the wall test specimens were constructed, they were infilled with concrete in two separate lifts with a construction joint at the joint between the base and the stem. Concrete infill was placed by pump and the walls were vibrated while filling to ensure all of the voids were filled. Lifting anchors were cast into the tops of the walls to facilitate removal after testing. Forms were stripped the next day and wall samples were left undisturbed for a minimum of seven days before testing.

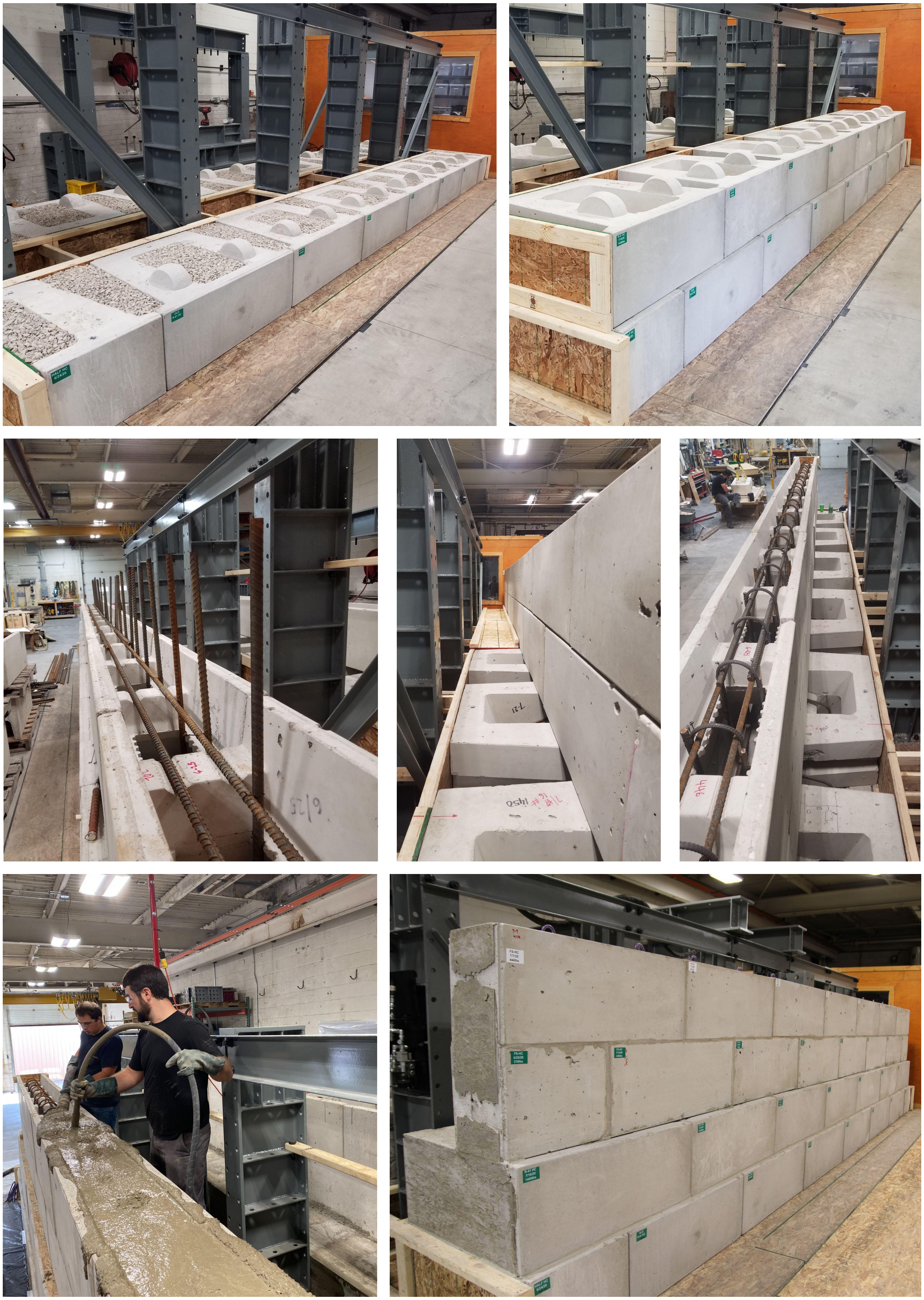

Figure 10 - Construction Photos of Barrier Walls

6.0 Testing Methodology

The intent of the test procedure was to verify the failure modes and static structural capacity of a full-scale section of the barrier wall. Two different end conditions were explored.

For Test Wall A, the stem of the wall was braced against lateral movement at each end (lateral flexural test). The foundation course, base of the wall, and the stem of the wall between the supports were free to move. Span between the supports was 25-feet (7,620 mm). A horizontal load was then applied to the wall stem to force a structural failure of the wall. The test set-up is illustrated in **Figures 11 and 13**.

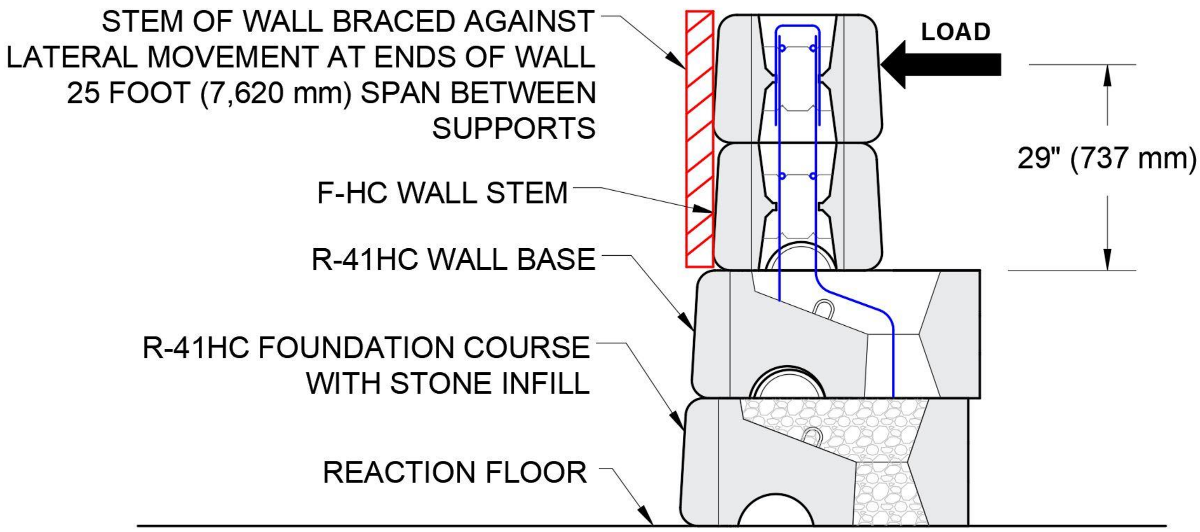

Figure 11 - Test A Set-up

For Test Wall B, the base of the wall, at the ends, was secured and prevented from sliding and overturning. The test wall was restrained from overturning by a large steel beam tied to the test frame. The test wall was restrained from sliding horizontally at the ends by a shear reaction plate bolted to the test floor to react against the inside edge of the groove on the bottom of the base block. The unsupported length of the wall section between the supports was 15-feet (4,572mm). A horizontal load was then applied to the wall stem to force a structural failure of the wall. The test set-up is illustrated in **Figures 12 and 13**.

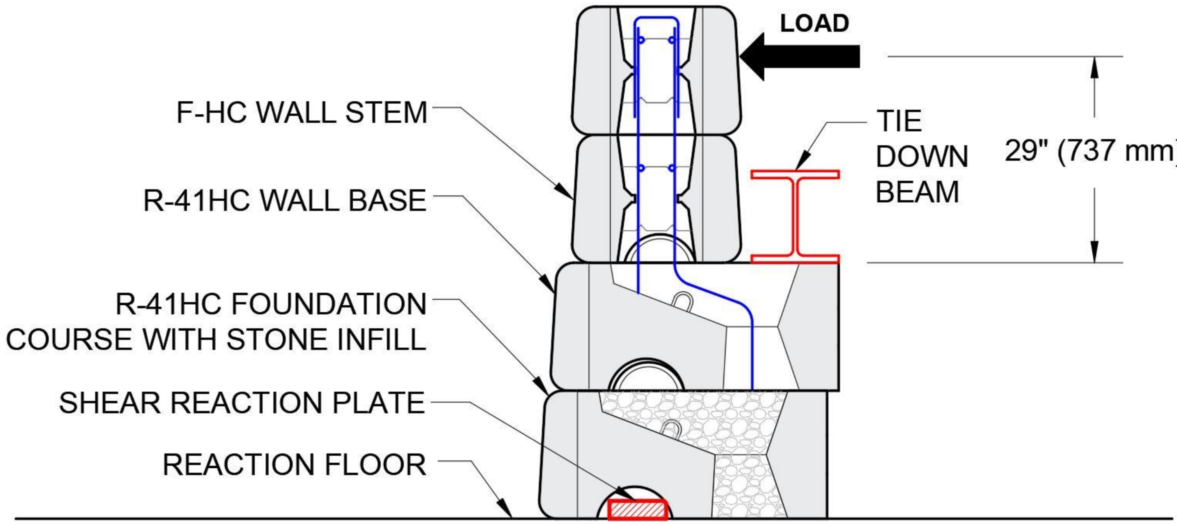

Figure 12 - Test B Set-up

Load was applied to the wall stem using two hydraulic actuators mounted horizontally in Aster Brands' structural test frame. The actuators were spaced horizontally 18-inches (457 mm) apart and were centered along the length of the wall specimen. Actuators pushed on the wall stem 29-inches (737 mm) above the top of the base block. See **Figure 13**. A 100 kilopound (445 kN) capacity load cell was installed at the end of the hydraulic actuator. A high-capacity roller with a spherical bearing was attached to the load cells and pushed against the wall allowing for rotation and vertical movement at the point of application of the load. Load was spread to the wall sample with an 8-inch (203 mm) wide by 12-inch (305 mm) tall by 1-inch (25 mm) thick steel plate backed with an 1-inch (25 mm) thick polyurethane bearing pad.

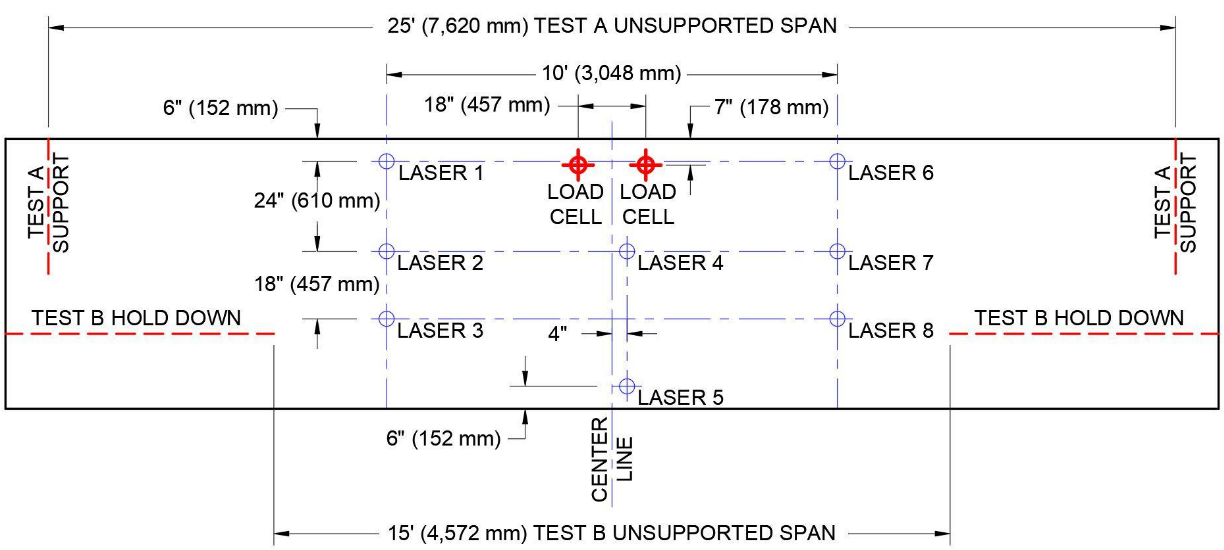

Figure 13 - Front view of test set-up

Horizontal displacement at the point of load was measured with an LDT displacement gauge mounted inside the hydraulic cylinder. Displacement at the point of load was also measured by two string potentiometer displacement gauges: one for each actuator. Horizontal displacements of the outside face of the wall were measured at eight locations with laser distance gauges: two points offset 4-inches (102 mm) from the center of the test and three points vertically spaced out 5-feet (1524 mm) on each side of the centerline of the test.

A preload of approximately 1,000 lbs (4.4kN) was applied to each wall sample to seat the wall in the test frame before recording displacements. The preload was held for approximately one minute before loading of the wall commenced. Displacement measurements were zeroed at the end of the preload period. Walls were then pushed until failure with a slowly increasing, pseudo-static, load-controlled rate of approximately 5,000 lb per minute (20.5 kN per minute), which correlated to an approximate 0.25 to 0.5 inch per minute (2.5 to 5 mm per minute) displacement rate of the actuator. This load rate was maintained until the wall failed and load dropped off significantly.

Test data was recorded at 1-second intervals with a National Instruments brand data acquisition system and Labview DAQ software. Load, displacement, load rate, horizontal actuator velocity, and time were recorded. In addition to this data, video was taken from multiple angles to evaluate failure modes of the wall assembly.

7.0 Results

Results from this test program can be seen in **Tables 2** and the graph shown in **Figure 14**. Load and deflection data (at the point of application of the load) was tabulated for two distinct points: yield and peak. Yield denotes a dip in the graph and corresponds to initial cracking in the wall section. Peak corresponds to the point of maximum load that the wall was able to sustain. The yield and peak points are annotated in **Figure 14**. In addition, deflections taken on the front of the wall with the laser distance measuring gauges are tabulated for the yield and peak points in **Table 3**.

Both walls exhibited a “yield line” type failure mechanism where the critical section angled from the stem-base interface up through the top of the wall (approximately 8-feet (2438 mm) wide at the top of the wall). **Figures 15** through **17** show failure of the wall sections.

Table 2 - Results

Test Wall	Yield Load lb (kN)	Deflection at Yield inch (mm)	Peak Load lb (kN)	Deflection at Peak inch (mm)	Notes
A	45,678 (243.2)	0.93 (24)	63,483 (282.4)	4.32 (110)	Stem wall at ends restrained from lateral movement. Flexural test.
B	47,208 (210.0)	0.85 (22)	70,329 (312.8)	2.44 (62)	Ends restrained from overturning and sliding.

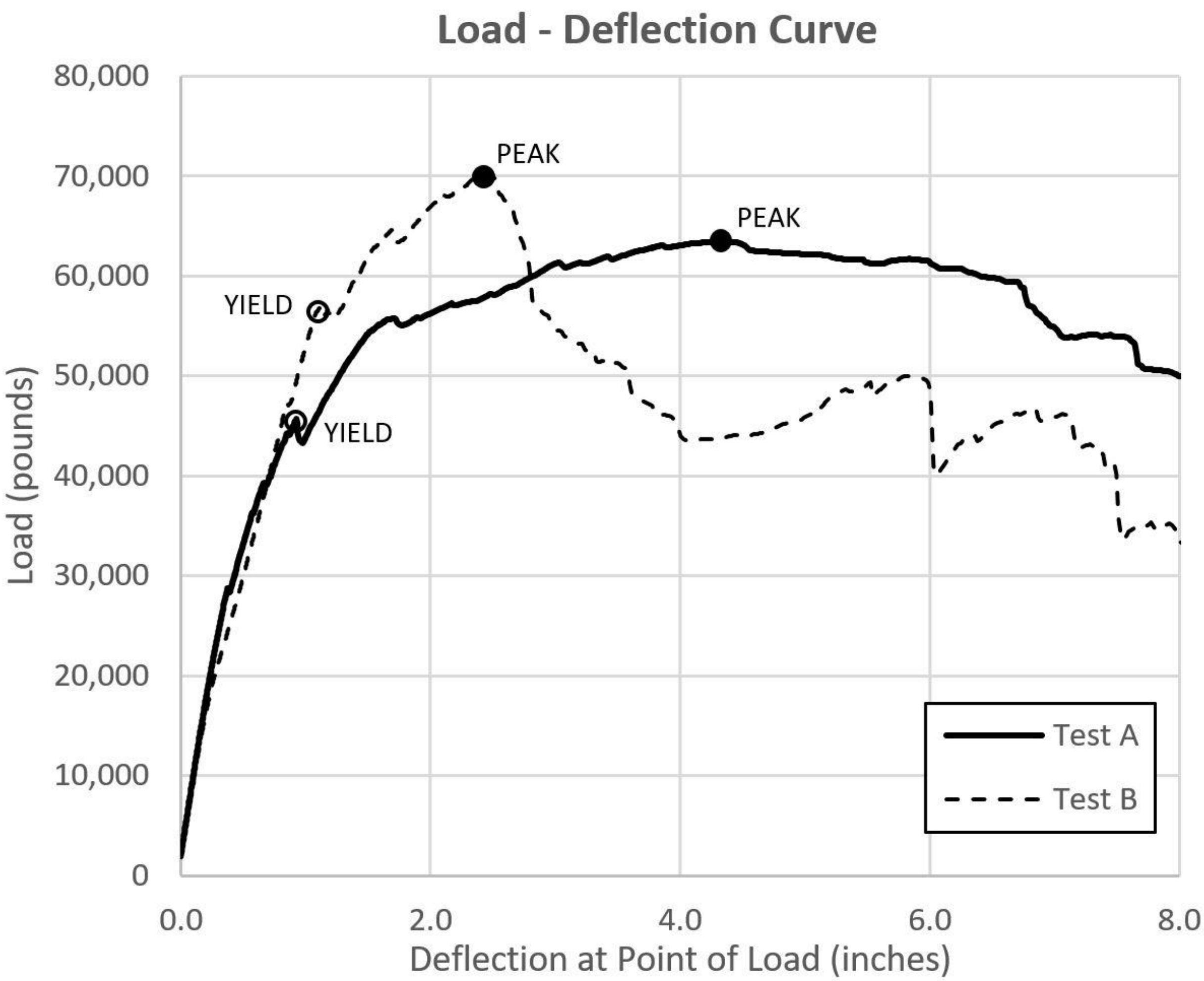

Figure 14 - Load Deflection Curve

Table 3 - Laser displacements

Test Wall A

Laser Number	Deflection at Yield inch (mm)	Deflection at Peak Load inch (mm)
1	1.04 (26)	2.81 (71)
2	0.61 (15)	2.66 (68)
3	1.04 (26)	2.21 (56)
4	0.85 (22)	4.59 (117)
5	0.43 (11)	2.81 (71)
6	1.48 (38)	3.35 (85)
7	1.55 (39)	2.88 (73)
8	1.49 (38)	2.55 (65)

Test Wall B

Laser Number	Deflection at Yield inch (mm)	Deflection at Peak Load inch (mm)
1	0.49 (13)	1.70 (43)
2	0.37 (9)	1.06 (27)
3	0.21 (5)	0.75 (19)
4	0.33 (8)	1.16 (29)
5	0.07 (2)	1.24 (31)
6	0.28 (7)	0.97 (25)
7	0.33 (8)	1.17 (30)
8	0.31 (8)	0.68 (17)

Figure 15 - Test Wall A

Figure 16 - Test Wall A

Figure 17 - Test Wall B

6.0 Closure

This data and conclusions should be used with care. The user should verify that project conditions are equivalent to laboratory conditions and account for variations.

This test data is accurate to the best of our knowledge. It is the responsibility of the user to determine suitability for the intended use.

ASTER BRANDS

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